IDENTIFYING HIGH-PRIORITY TECHNOLOGY DEVELOPMENTS FOR LOW-COST PLANETARY EXPLORATION MISSIONS

15 **April 1994**

(A Summary of work for NASA by David H. Collins, Steven E. Johnson, Donald Rapp, et al.)

Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California 91109

THE WORK REFERRED TO IN THIS PRESENTATION WAS SPONSORED BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, OFFICE OF SPACE SCIENCE AND IS REPORTED IN JPL INTERNAL DOCUMENT D-1 1113.

STUDY OBJECTIVES

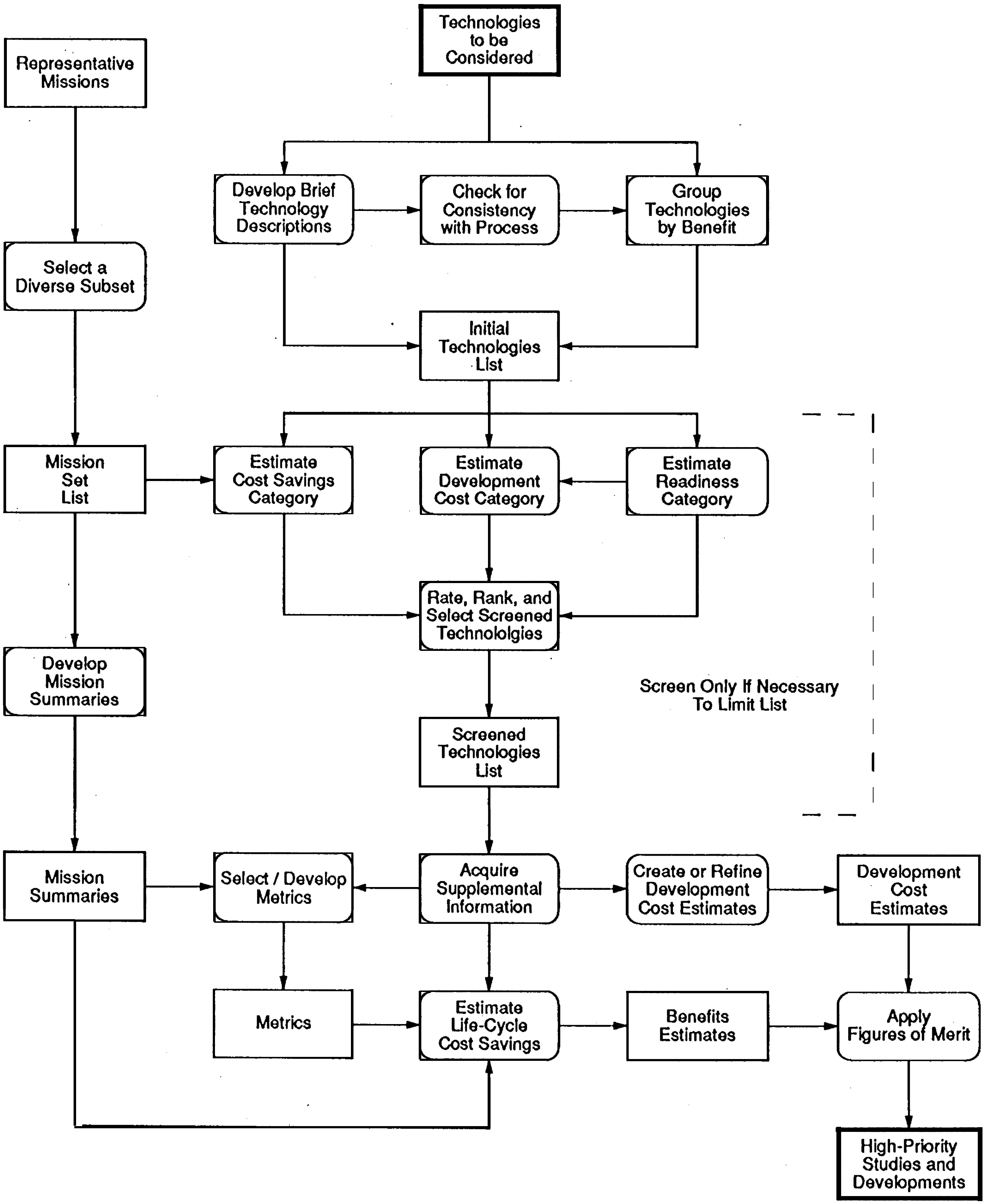
DEVISE A PILOT PROCESS FOR NEW TECHNOLOGY ASSESSMENT AND IDENTIFICATION OF STUDY AREAS AND DEVELOPMENTS THAT SHOULD BE HIGH PRIORITIES FOR THE NASA SOLAR SYSTEM EXPLORATION DIVISION

USE THE PROCESS TO EVALUATE AN EXAMPLE LIST OF TECHNOLOGIES AND RECOMMEND HIGH-PRIORITY DESIGNATIONS AS APPROPRIATE

THE PILOT TECHNOLOGY ASSESSMENT PROCESS DEVELOPED

- GENERATE AN INITIAL TECHNOLOGIES LIST
    - DEVELOP A BRIEF DESCRIPTION FOR EACH TECHNOLOGY CONSIDERED
    - REVIEW AND REMOVE TECHNOLOGIES INCONSISTENT WITH THE PROCESS CAPABILITIES OR ASSESSMENT RESOURCES
    - GROUP TECHNOLOGIES BY BENEFIT
- SELECT / DEVELOP AND DESCRIBE A REPRESENTATIVE BUT DIVERSE SET OF MISSIONS
- IF NECESSARY, SCREEN THE TECHNOLOGIES FOR PROMISING CANDIDATES, LIMITING THE TOTAL NUMBER TO THAT WHICH CAN BE EVALUATED IN DEPTH
    - CATEGORIZE COST SAVING, DEVELOPMENT COST, AND READINESS LEVELS EACH AS LOW, MEDIUM, OR HIGH
    - RATE, RANK, AND SELECT TECHNOLOGIES FOR FURTHER CONSIDERATION
- ACQUIRE SUPPLEMENTAL INFORMATION ON SELECTED TECHNOLOGIES
- SELECT / DEVELOP METRICS BASED ON THE TECHNOLOGIES AND MISSIONS
- ESTIMATE THE LIFE-CYCLE COST BENEFIT FOR EACH SELECTED TECHNOLOGY
- ESTIMATE, WHERE FEASIBLE, THE DEVELOPMENT COST FOR EACH SELECTED TECHNOLOGY
- APPLY FIGURES OF MERIT TO IDENTIFY HIGH-PRIORITY STUDIES AND DEVELOPMENTS
- RECOMMEND THESE STUDIES AND DEVELOPMENTS TO NASA

THE PILOT TECHNOLOGY ASSESSMENT PROCESS



THE EXAMPLE ASSESSMENT

- THE ASSESSMENT STARTED WITH 73 TECHNOLOGIES
- REVIEW AND GROUPING BY BENEFIT REDUCED THE NUMBER TO 65
    - IN THE INITIAL TECHNOLOGIES LIST
- MISSIONS SELECTED / DEVELOPED AND DESCRIBED INCLUDED*:
    - NEAR EARTH OBJECT FLYBY (NEOF), E. G., "ACME-3"
    - OUTER SOLAR SYSTEM FLYBY **(OSSF),** E.G., "PLUTO FAST FLYBY"
    - NEAR EARTH OBJECT RENDEZVOUS **(NEOR),** E. G., "NEAR"
    - INNER SOLAR SYSTEM ORBITER (1SS0), E. G., A MERCURY ORBITER
    - OUTER SOLAR SYSTEM LANDER **(OSSL),** E. G., "MESUR NETWORK"
    - SAMPLE RETURN **(SR),** E. G., FROM MARS
- TEN PROMISING TECHNOLOGIES WERE SELECTED IN THE SCREENING PROCESS
- METRICS SELECTED AND DEVELOPED INCLUDED:
    - LAUNCH COST SAVINGS AS A FUNCTION OF FLIGHT SYSTEM DRY MASS SAVINGS
    - LAUNCH COST SAVINGS FOR 5'%0 INCREASE IN FLIGHT SYSTEM SPECIFIC IMPULSE
    - FLIGHT SYSTEM COST SAVINGS AS A FUNCTION OF FLIGHT SYSTEM POWER SAVINGS
    - FLIGHT SYSTEM COST SAVINGS AS A FUNCTION OF DOWNLINK DATA REDUCTION

• A Venus lander was also included in the mission set list. It was used in the screening process but excluded in the more detailed assessment. This was because" only the lander, not the carrier vehicle was included in the list, and this was not consistent with the needs of the detailed assessment process.

THE EXAMPLE ASSESSMENT
(Sheet 2 of 3)

- LIFE-CYCLE COST BENEFITS WERE ESTIMATED FOR EACH TECHNOLOGY
  - HIGHLY EXPERIENCED ENGINEERS SUPPORTED THE ESTIMATION PROCESS WITH:
    - 7 INDIVIDUAL ESTIMATES OF FLIGHT SYSTEM COST SAVINGS FOR EACH MISSION
    - 7 OR 8 INDIVIDUAL ESTIMATES OF DRY MASS **SAVINGS** FOR EACH MISSION
      - METRICS THEN CONVERTED THESE TO LAUNCH COST SAVINGS*
    - 3 INDIVIDUAL ESTIMATES OF MISSION OPERATIONS COST SAVINGS FOR EACH MISSION
  - EACH SET OF THESE INDIVIDUAL ESTIMATES WAS THEN AVERAGED ACROSS THE **MISSION** SET, PRODUCING AN ESTIMATE OF **SAVINGS** PER **MISSION**
  - MEDIAN ESTIMATES OF COST SAVINGS PER MISSION WERE THEN TOTALED FOR FLIGHT SYSTEM, LAUNCH, AND MISSION OPERATIONS
- TECHNOLOGY DEVELOPMENT COST ESTIMATES WERE MADE FOR 4 OF THE TECHNOLOGIES
  - IN 2 CASES THERE WAS INSUFFICIENT INFORMATION FOR A COST ESTIMATE
  - IN THE REMAINING 4 CASES, THE FINAL ASSESSMENT CONCENTRATED ON THE GENERAL CASE (NOT A SPECIFIC IMPLEMENTATION) PREVENTING COST ESTIMATION

* METRICS WERE ALSO USED IN ESTIMATING THE LAUNCH COST **SAVINGS** FROM HIGHER **Isp** AND FOR CHECKING THE BENEFITS FOR REDUCING THE NEEDED **DOWNLINK** DATA RETURN.

THE EXAMPLE ASSESSMENT

(Sheet 3 of 3)

- FIGURES OF MERIT APPLIED AND RESULTING RECOMMENDATIONS WERE AS FOLLOWS:
  - RECOMMENDED FOR HIGH-PRIORITY STUDY; S ≥ \$5 M / MISSION, C NOT DEFINED
    - HIGH-RATIO DOWNLINK DATA REDUCTION
    - HIGH-DENSITY ELECTRONICS PACKAGING
    - HIGH-DENSITY DATA STORAGE
  - RECOMMENDED FOR HIGH-PRIORITY STUDY; 3 > {(RLS/C)-1} ≥ 2
    - LOWER MASS, SAFER PYROTECHNICS INITIATION
    - FULL CONTROL OF HEAT PIPE CONDUCTANCE
  - RECOMMENDED FOR HIGH-PRIORITY DEVELOPMENT; {(RLS/C)-1} ≥ 3
    - HIGH-ENERGY-DENSITY RECHARGEABLE BATTERIES
    - BIPROPELLANT ENGINES WITH IMPROVED Isp

R = AVERAGE **RATE** OF MISSIONS (IN **MISSIONS** PER YEAR)

L = AVERAGE BENEFICIAL **LIFETIME** OF TECHNOLOGIES OR PERIOD OF INTEREST (IN YEARS)

S = TOTAL OF MEDIAN COST **SAVINGS** ESTIMATES (IN **M\$** PER MISSION)

C = ESTIMATED TECHNOLOGY DEVELOPMENT **COST** (IN **M\$**) TO FLIGHT READINESS

Notes: The RL product used in this example was 6. Fixed-year (FY '93) dollars were used in **M\$.**

ACKNOWLEDGEMENTS

This study was carried out by the Jet Propulsion Laboratory, California Institute of Technology and was sponsored by the National Aeronautics and Space Administration, Office of Space Science, Solar System Exploration Division. Specific contributions to the study were as follows:

JPL Program Office Sponsor -- Joel Sercel

Study Task Manager and Lead -- David Collins

Technology Identification, Description, and Cost Estimation -- Don Rapp (Lead) and

Gaj Birur	Joe Maserjian	Mark Underwood
Marty Herman	Bob Miyake	Pat Waddell
Jim Layland	Paul Stella	Joe Yuen
Jim Lesh	Frank Surber	(et al.)

Technology Screening Benefits Estimators -- David Collins and Steve Johnson

Selected Technologies Benefits Estimators for Flight System Mass and Cost Savings --

Steve Bailey -- NASA/JSC
Curt Cleven
Ron Draper
Alan Friedlander, Mark Jacobs, John Niehoff -- SAIC
Scott Hubbard, Marcus Murbach, George Sarver -- NASA/ARC
Bill Layman
Jim Marr
Harry Norton
Dave Skillman -- NASA/GSFC
Neil Yarnell

Selected Technologies Benefits Estimators for Mission Operations Cost Savings --

Barbara Anderson, John Carraway, and Ray Morris

Metrics -- David Collins, Steve Johnson (Lead), Lilac Muller, and Leigh Rosenberg

The authors thank the many individuals who have assisted them in the course of the study as it led up to publication of the 29 November 1993 draft final report. In addition, we thank Joel Sercel and, from SAIC, Corinne Buoni, Mark Jacobs, and Mike Stancati for their comments and suggestions related to the draft report.